CHARGING AHEAD:

How to Find Powerful Rechargeable Batteries That Go On and On…and On

A Report by the Responsible Purchasing Network
to the San Francisco Department of the Environment

Recommending Specifications for AA, AAA and D-Sized
Rechargeable Batteries for San Francisco's SF Approved Program

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The primary purpose of this report, *Charging Ahead*, is to recommend specifications for three sizes of rechargeable consumer batteries (AA, AAA and D) based on a review of available literature and an assessment of the technical and marketing information of available products. It includes:

- **Overview and History of Rechargeable Batteries**
- **Recommended Specifications for Rechargeable Batteries** that identify the battery chemistry (NiMH), the minimum power rating of the battery (measured in milli-amp-hours) and the maximum self-discharge rate of qualifying products. The specifications, which are based on RPN's in-depth comparison of NiMH consumer batteries currently on the market can be met by at least three brands of batteries in each size category.
- **Best Practices for Procuring and Using Rechargeable Batteries**
- **Comparison of Battery Chemistry Types** describes the relative availability as well as the performance advantages and disadvantages of each type of rechargeable battery in the US marketplace and compares them to standard, single-use alkaline batteries.
- **Glossary of Terms**
- **Applicable Standards**
- **Cost Comparisons** of AA NiMH rechargeable batteries with single-use alkaline batteries
- **Report References**
- **Appendix A: Benchmarking Assessment**, which describes several federal agencies, local governments, state agencies and universities that have evaluated or pilot tested rechargeable batteries for their operations.
- **Appendix B: Contacts** interviewed or communicated with via email for during the development of this report.
- **Appendix C: Nickel-Metal Hydride AA, AAA and D Batteries** (in a separate spreadsheet).

OVERVIEW AND HISTORY OF RECHARGEABLE BATTERIES

Overview

Nickel-metal hydride (NiMH) rechargeable batteries have become the most commonly used type of consumer battery on the market because they:

- Are available in a standard consumer-battery sizes such as AA, AAA, C, D and 9V;
- Discharge power at a voltage (1.2V) that is similar to that of standard alkaline batteries; therefore, they work well in most battery-operated devices (except emergency/safety equipment);
- Have an equivalent amount of capacity – or juice – measured in milli-Amp-hours (mAh) to standard alkaline batteries (so their charge lasts about as long as standard alkaline batteries);
- Are now available with low-self-discharge (LSD) technology, which prevents their charge from trickling out over time while they are being stored or used in low-drain devices such as clocks);
- Do not suffer from "the Memory Effect", which reduces a battery's capacity when it is not fully discharged before re-charging;
- Often are available (partially) pre-charged, making them available for use right out of the package; and
- Are affordable and offer an opportunity for cost savings over a relatively short period of time.

The performance attributes of NiMH rechargeable batteries on the market vary greatly. Consequently, specifications are needed to identify products that are most likely to perform well.

- Some rechargeable NiMH batteries have a significantly higher capacity (mAh) rating than others of the same size. Rechargeable batteries with a higher capacity rating are likely to last longer between charges.

- While some products have the LSD technology, others do not. And, in some cases, it is difficult to determine whether the product utilizes LSD technology or not based on the information provided by the manufacturer. Because there is no standard definition of LSD technology, RPN created ist LSD specification based on available technical data.

- Some rechargeable batteries have claims that they can recharged significantly more times than others. The maximum number of charges claimed ranges from 400 to 3000. Unfortunately, the claims about the number of times a battery can be charged are often vague (e.g., can be charged hundreds of time) or missing. Therefore, this criterion was not included in the recommended specifications.

Finally, while several government agencies have evaluated rechargeable batteries for their operations, few have used high-capacity NiMH batteries with LSD technologies. Consequently, while these pilot tests have yielded some positive results, more are needed to document the benefits of the best NiMH products available in today's markets.

History of Rechargeable Batteries

Nickel-metal hydride batteries predominate among today's rechargeable consumer batteries, almost entirely replacing the earlier nickel-cadmium (NiCd) batteries. The NiMH batteries pack higher capacities and virtually eliminate the "memory effect" that had previously limited NiCd performance. According to Battery University:

> *For many years, NiCd was the only rechargeable battery for portable applications. In the 1990s, environmentalists in Europe became concerned about the harm incurred when NiCd is carelessly disposed. The Battery Directive 2006/66/EC now restricts the sale of NiCd batteries in the European Union except for specialty industrial use for which no replacement is suitable. The alternative is nickel-metal hydride (NiMH), a more environmentally friendly battery that is similar to NiCd.*[1]

In 2005, an innovative "low self-discharge" (LSD) version of NiMH batteries was introduced into the US marketplace. It greatly decreases the battery's energy drain during storage and usually is shipped pre-charged (although not fully charged), which makes it ready to use immediately, thus resolving two major drawbacks to using rechargeable batteries. Over the past decade, the power and performance of NiMH rechargeable batteries with LSD technology has continued to improve. Consequently, they are now the most versatile and reliable choice for consumer battery use.

RPN evaluated many brands of NiMH rechargeable batteries that are labeled – or marketed with – an LSD claim in order to develop a set of high-performance specifications for AA, AAA and D rechargeable batteries for the City and County of San Francisco. Because there appears to be no standardized definition of "low self discharge," the authors reviewed the technical performance of LSD products to develop an appropriate specification. This specification, requiring a rechargeable battery to retain at least 80% of its capacity after 1 year of storage, or 75% after 3 years of storage, means that a NiMH battery with LSD technology will be strong and ready to use even after a year of non-use, similar to a single-use alkaline battery.

In addition, rechargeable batteries rated with a higher milli-amp-hour (mAh) rating will last longer than those with a lower mAh rating. The higher mAh batteries will also perform best with high-drain equipment such as cameras, often comparable to or exceeding the performance of disposable alkaline batteries. Purchasers that put rechargeable batteries into immediate use and recharge them frequently may not be concerned about storage capacity and, instead, favor higher mAh ratings. NiMH AA rechargeable batteries range from 1000 to 2800 mAh, which is clearly identified on the batteries. This overlaps with the range of many standard single-use alkaline AA batteries, which have a nominal capacity of 2500 to 3000 mAh[2]. However, the intricacies of

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[1] "BU-101: When Was the Battery Invented," *Battery University, http://batteryuniversity.com/learn/article/when_was_the_battery_invented*

[2] The capacity ratings of standard alkaline batteries are not on the batteries themselves, but can sometimes be found on technical data sheets.

standard alkaline battery chemistry tend to yield significantly less when they are used in high-drain devices.[3]

While NiMH rechargeable batteries are offered with a wide variation in mAh ratings, they all have the same voltage, 1.2V. Because of battery chemistry and performance differences, the rechargeable batteries are considered equivalent to 1.5V single-use, alkaline batteries, which quickly drop in voltage and then continue to decrease below 1.2V during their use. In contrast, rechargeable batteries remain steady at 1.2V for at least 80% of each charge cycle and then drop quickly at the end. This is often a distinct advantage of rechargeables because their power remains steady over time. However, rechargeable batteries are generally not recommended for use in emergency equipment and voltmeters, which are typically calibrated specifically for the sloping voltage decline of alkaline batteries and, therefore, cannot accurately indicate when rechargeable batteries are nearing the end of their charge.

Other types of rechargeable batteries that have not gained a significant amount of market share include rechargeable alkaline batteries (which can be recharged far fewer times than NiMH batteries, only about 50 times), nickel-zinc rechargeable batteries (which have a capacity and longevity that are lower than that of nickel-metal hydride batteries), and lithium ion batteries (which operate at much higher voltage and are typically available only in nonstandard sizes, preventing them from being a direct replacement for most applications).

RECOMMENDED SPECIFICATIONS FOR RECHARGEABLE BATTERIES

Next, RPN evaluated approximately 60 AA, AAA and D NiMH rechargeable battery products available in the US marketplace to develop a set of high-performance specifications for the City and County of San Francisco.

- First, after comparing available rechargeable battery technologies, RPN concluded that nickel-metal hydride (NiMH) batteries with low self-discharge (LSD) technology are the best drop-in replacement for single-use, alkaline consumer batteries.

- Second, RPN compared AA, AAA and D NiMH rechargeable batteries to develop performance requirements that differentiate them based on how much capacity (or energy) they have when they are fully charged AND how effective they are at staying charged over time.

    - NiMH rechargeable batteries with a higher capacity rating – measured in milli-amp-hours (mAh) – will last longer than those with a lower mAh rating. The higher mAh NiMH rechargeable batteries, which often meet or exceed the performance of disposable alkaline batteries, are also more versatile than NiMH batteries with a lower mAh rating since they can be used in high-drain equipment such as cameras, paper towel dispensers, and non-LED flashlights as well as low-

[3] *Alkaline Manganese Dioxide Handbook and Application Manual*, *Energizer*, Version: Alk2.0, 2008-2012, http://data.energizer.com/PDFs/alkaline_appman.pdf

drain equipment such as clocks and computer "mice". For most rechargeable batteries, there is information available indicating its capacity. By comparing the capacity ratings of 22 AA rechargeable NiMH batteries, RPN was able to identify a reasonable cut-off below which the battery would be considered too weak to be acceptable.

- Because there appears to be no standardized definition of "low self-discharge," RPN reviewed the technical performance information relating to the self-discharge rate of the same NiMH rechargeable batteries to develop the following technical requirement for the specifications:

  "Maintains a minimum of 80% capacity after 1 year storage, or 75% after 3 years storage."

  Many rechargeable NiMH batteries with LSD technology have a comparable charge to alkaline batteries and maintain their charge – much like an alkaline battery – when they are left in storage in between uses or are used in low-drain electronics for an extended period of time without being recently charged.

- Some NiMH rechargeable batteries have a very high mAh capacity rating, but do not have an LSD claim or have a vague claim about the ability of the product to hold a charge over time (e.g., "charge lasts up to 12 months in storage," "ready to use for up to 1 year"). And, it is not clear the extent to which there is a tradeoff between these two performance attributes. Purchasers that recharge their batteries frequently and use them soon after doing so may favor products with higher mAh ratings even if they do not have LSD technology (since any drainage during that time interval would be minimal.)

RPN's recommended specifications do not include a minimum number of charges that the battery must be able to provide because information on this performance attribute was not consistently available. Also, when it was provided it was either vague (e.g., "replaces hundreds of batteries") or varied widely among brands (ranging from 400 charges to as many as 3000 charges). It would be possible to include a minimum number of charges the battery must provide; however, that could narrow the field of products that would meet the specifications and also would not guarantee that a higher number of recharges continue to return the batteries to their original full capacity. A disadvantage of some rechargeable batteries is that at the end of their multi-charge lifetime, they will hold their charge for shorter periods.[4]

In addition, the specifications do not include a requirement for the battery to come pre-charged. Early on in the investigation it seemed that seeing a product labeled as "pre-charged" was an indicator that it used LSD technology. And, indeed most NiMH batteries with LSD technology do claim to be pre-charged. However, it is not clear that all pre-charged NiMH batteries do use LSD technology, and some NiMH batteries with LSD technology do not come pre-charged. Therefore, we did not require it to be included in the specifications. If it is important for SF departments to have rechargeable batteries come shipped pre-charged, that requirement could easily be added to the specifications, but not as an alternative to demonstrating that the product

[4] *REI Batteries: How To Choose*, http://www.rei.com/learn/expert-advice/batteries.html, accessed May 3, 2015

uses LSD technology. It is also important that SF departments understand that pre-charged batteries, while ready to use immediately, are not shipped fully charged.

Recommended Specifications for AA Rechargeable Batteries

- Nickel-metal hydride (NiMH) chemistry
- Minimum 2000 mAh
- Low self-discharge (LSD): Maintains a minimum of 80% capacity after 1 year in storage, or 75% after 3 years in storage

RPN identified and analyzed 22 different AA NiMH rechargeable batteries in the US marketplace for this report. Their capacity ratings vary widely, ranging from 1000 mAh to 2800 mAh. At least 10 of these products meet our recommended AA rechargeable battery specifications. See a list of compliant products listed in the table below, with the products with the highest capacity rating at the top.

Brand	**Product Name**	**Capacity (mAh)**	**LSD Claim**
1. Aibocn	EBL High-Capacity AA NiMH Precharged Rechargeable Batteries, 1500 Cycle	2800	Can maintain 75% of capacity after 3 years of non-use
2. Panasonic	Eneloop Pro AA High Capacity New Ni-MH Pre-Charged Rechargeable Batteries (Black label)	2550	Retains 85% of charge for 1 year when not in use
3. Sanyo	Eneloop 1.2V, 2500 mAh Rechargeable Batteries	2500	Maintains 75% charge after 1 year of non-use
4. PowerEx	Imedion Low Self-Discharge AA 2400 mAh Rechargeable Batteries	2400	Keeps up to 85% of charge after 1 year of storage
5. Duracell	Rechargeable Staycharged/Duralock AA Batteries	2400	Retains 80% of its charge after 12 months of storage
6. Amazon Basics	AA High-Capacity Pre-charged Rechargeable Batteries	2400	Stays 80% charged even after a full year of non-use
7. Sanyo	Eneloop AA Rechargeable Batteries	2000	Retains 85% of its charge for 1 year when not in use
8. Panasonic	Eneloop AA New 2100 Cycle Rechargeable Batteries (White label)	2000	Retains 90% of its charge for 1 year
9. Tenergy	Centura Low Self-Discharge AA Nickel-Metal Hydride Rechargeable Batteries	2000	Very slow self discharge; maintains 85% capacity after 1 year of storage and 70% residual capacity after 2 years of storage
10. Amazon Basics	AA Rechargeable Batteries	2000	Maintains 75% after 3 years

In addition, at least another six (6) products meet the minimum mAh requirement in the specifications but do not appear to use LSD technology or do not provide enough information to be able to substantiate that it meets RPN's definition of LSD. These products, some of which *may* pass, are listed in the table below.

Brand	**Product Name**	**Capacity (mAh)**	**LSD Claim**
1. SunLabz	AA Rechargeable Batteries with 2800 mAh	2800[5]	Extremely gradual self-discharge, maintains 80% of capacity
2. Lenmar	Nickel-Metal Hydride AA NoMem Rechargeable Batteries	2700	Not enough information provided about ability of battery to maintain charge over time
3. PowerEx	MHRAA4 Rechargeable NiMH Batteries	2700	Not enough information provided about ability of battery to maintain charge over time
4. AA Portable Power Corp.	Powerizer AA Rechargeable Batteries	2600	Not enough information provided about ability of battery to maintain charge over time
5. Tenergy	Premium AA Nickel-Metal Hydride Rechargeable Batteries	2500	Not enough information provided about ability of battery to maintain charge over time
6. Energizer	Recharge Power Plus AA4 Rechargeable Batteries	2300	Charge lasts up to 12 months in storage

A purchaser might consider some of these non-LSD products to be perfectly acceptable in certain situations. In particular, the highest mAh batteries (e.g., those with 2500-2800 mAh) would provide the greatest capacity, potentially offsetting drainage losses if the battery will be recharged often.

[5] SunLabz also has a similar product with only 2600 mAh. It may be an older product still offered on the market.

Finally, it is important to note that four (4) products failed because they do not meet the minimum 2000 mAh requirement for AA rechargeable batteries in our proposed specifications. These products are listed in the table below.

Brand	Product Name	Capacity (mAh)	LSD Claim
1. Energizer	Recharge Universal Batteries	1400	Charge lasts up to 12 months in storage
2. Rayovac	Recharge Rechargeable Batteries	1350	Not enough information provided about ability of battery to maintain charge over time
3. Eveready	Rechargeable AA Batteries	1300	Ready to use for up to 1 year
4. Panasonic	Eneloop Lite AA Rechargeable Batteries (with blue label)[6]	1000	Retains 65–70% capacity after five years in storage

A spreadsheet detailing the attributes of the 22 AA NiMH rechargeable batteries that were analyzed for this report can be found in Appendix C (see tab labeled "AA Batteries").

Recommended Specifications for AAA Rechargeable Batteries

- Nickel-metal hydride (NiMH) chemistry
- Minimum 800 mAh
- Low Self-Discharge: Maintains a minimum of 80% capacity after 1 year storage, or 75% after 3 years storage

We identified and analyzed 16 different AAA NiMH rechargeable batteries in the US marketplace for this report. Their capacity ratings vary widely, ranging from 500 mAh to 1100 mAh. Of these, at least nine (9) products meet the proposed AAA rechargeable battery specifications. See a list of compliant products listed in the table below, with the products with the highest capacity rating at the top.

Brand	Product Name	Capacity (mAh)	LSD Claim
1. Aibocn	EBL 1500 Cycle 1100 mAh AAA Rechargeable Batteries	1100	Improved low self-discharge still maintains 75% capacity after 3 years of non-use
2. PowerEx	Imedion Low Self- Discharge 950 mAh AAA Rechargeable Batteries	950	Keeps up to 85% of charge after 1 year of storage
3. Panasonic	Eneloop Pro High-Capacity Ready to Use AAA Rechargeable Batteries	950	Holds 85% charge up to 1 year
4. Duracell	Duracell AAA Rechargeable Batteries	850	Holds 80% of charge after 1 year
5. Tenergy	Centura NiMH AAA 800 mAh Low Self Discharge Rechargeable Batteries	800	Keeps 85% after 12 months, 70% after 24 months
6. Sanyo	Eneloop AAA Rechargeable Batteries	800	Holds 85% charge up to 1 year

[6] This "economy" rechargeable battery has a capacity of only 1000 mAh. Interestingly, this product has the highest number of potential recharges claimed by any manufacturer (up to 3000); this may mean that there is a trade-off between capacity and recharge capability. This lower-mAh option was developed by Eneloop to provide a more economical choice for low-drain equipment such as clocks.

7. Panasonic	Eneloop Ready to Use AAA Rechargeable Batteries (New 2100 Cycle)	800	Holds 85% charge up to 1 year
8. Amazon Basics	AAA Rechargeable Pre-charged Batteries (white label)	800	Batteries have a low self-discharge technology; Maintain 80% of charge after 1 year, 70% after 3 years
9. Aibocn	800 mAh AAA Rechargeable Batteries	800	Improved low self-discharge still maintains 75% capacity after 3 years of non-use

In addition, at least another four (4) products meet the minimum mAh requirement of 800 mAh but do not appear to use LSD technology or do not provide enough information to be able to substantiate that it meets the definition of LSD in the proposed RPN specifications. These products, some of which *may* pass, are listed in the table below.

Brand	**Product Name**	**Capacity (mAh)**	**LSD Claim**
1. PowerEx	MHRAAA4 Rechargeable AAA NiMH Batteries	1000	Not enough information provided
2. SunLabz	AAA Rechargeable Batteries	1000	Extremely gradual self-discharge; maintains 80%
3. Rayovac	Recharge Plus Rechargeable Batteries	900	Not enough information provided
4. Amazon Basics	AAA Rechargeable Batteries (black label)	800	Extremely gradual self-discharge maintains 80%

A purchaser might consider these non-LSD brands to be perfectly acceptable in certain situations. In particular, the highest mAh batteries (e.g., those with 1000 mAh) would provide the greatest capacity, potentially offsetting drainage losses if the battery will be recharged often.

Finally, it is important to note that three (3) products failed because they do not meet the minimum capacity requirement of 800 mAh for AA rechargeable batteries in our proposed specification. These products are listed in the table below.

Brand	**Product Name**	**Capacity (mAh)**	**LSD Claim**
1. Energizer	AAA4 Recharge Power Plus Rechargeable Batteries	700	Stays charged up to 1 year
2. Rayovac	Recharge Rechargeable 600 mAh NiMH Pre-charged Batteries	600	Stays charged up to 5 years when not in use
3. Eveready	Rechargeable AAA Batteries	500	Ready to use for up to 1 year

A spreadsheet detailing the attributes of the 16 AAA rechargeable batteries that were analyzed for this report can be found in Appendix C (see tab labeled "AAA Batteries").

Recommended Specifications for D Rechargeable Batteries

- NiMH chemistry
- Minimum 8000 mAh
- Low Self-Discharge: Maintains a minimum of 80% capacity after 1 year in storage, or 75% after 3 years in storage

We identified and analyzed 14 different D-sized NiMH rechargeable batteries in the US marketplace for this report. Their capacity ratings vary widely, ranging from 2200 mAh to 12,000 mAh. Metaefficient.com, a commercial entity, compared available D-cell rechargeable batteries in 2015 and concluded:

> *The best rechargeable D size batteries are the new LSD Ni-MH (low self-discharge Nickel-Metal Hydride) cells. These new Ni-MH rechargeable batteries are able to retain a charge for a year, making them suitable for using in flashlights and other low-term applications.*[7]

Low self-discharge (LSD) technology is not as common with rechargeable D-cell batteries as it is with AAs and AAAs. Still, at least three (3) rechargeable D battery brands meet the specifications. See a list of compliant products listed in the table below, with the products with the highest capacity rating at the top.

Brand	Product Name	Capacity (mAh)	LSD Claim
1. Aibocn	2 in 1 EBL® 10000mAh D Cell Ni-MH Rechargeable Batteries	10,000	Maintains 75% of capacity after 3 years of non-use
2. PowerEx	Imedion Ready to Use D9500 mAh Rechargeable Batteries	9500	Retains up to 85% of its charge after 1 year
3. Tenergy	Centura D Size Low Self-Discharge Rechargeable Batteries	8000	85% after 1 year, 70% after 2 years

In addition, at least another five (5) products failed to meet RPN's proposed specifications because, while they meet the minimum mAh requirement, they do not appear to use low self-discharge technology or do not provide sufficient information to enable us to substantiate it. These products, some of which *may* pass, are listed in the table below.

Brand	Product Name	Capacity (mAh)	LSD Claim
1. X2 Power	X2PD-2 Rechargeable Batteries	12,000	Not enough information provided about ability of battery to maintain charge over time
2. PowerEx	Powerex D 11000mAh, LR20 Rechargeable Batteries	11,000	Not enough information provided about ability of battery to maintain charge over time
3. Tenergy	Premium D-Cell Rechargeable Batteries	10,000	Not enough information provided about ability of battery to maintain charge over time
4. SunLabz	10000 mAh NiMH D Rechargeable Batteries	10,000	Extremely gradual self-discharge, maintains 80% of capacity

[7] "The Best Low Self-Discharge Rechargeable D Size Batteries: Imidion by Maha/PowerEx", *The Best Rechargeable Batteries of 2015*, MetaEfficient.com, http://www.metaefficient.com/rechargeable-batteries/rechargeable-d-size-batteries-chargers.html

5. FlePow	FlePow High-Capacity Low Self-Discharge D-Cell Rechargeable Batteries	8,000	Low self-discharge rate; maintains 80% capacity for 1 year storage and 70% for 2 years

A purchaser might consider these non-LSD brands to be perfectly acceptable in certain situations. In particular, the highest mAh D-cell rechargeable batteries (e.g., those with 10,000 – 12,000 mAh) would provide the greatest capacity, potentially offsetting drainage losses if the battery is recharged often such as in automatic paper towel dispensers that are in a heavy use area.

Finally, it is important to note that six (6) products failed because they do not meet the minimum capacity requirement of 8000 mAh for D-cell rechargeable batteries in our proposed specification. These products are listed in the table below.

Brand	**Product Name**	**Capacity (mAh)**	**LSD Claim**
1. Eneloop	Eneloop D-Size Rechargeable Batteries[8]	5700	Not enough information provided
2. RadioShack	Enercell 1.2V/5000 mAh NiMH D Rechargeable Batteries	5000	Not enough information provided
3. Nuon	Nured-2LS NiMH D Rechargeable Batteries	3000	Not enough information provided
4. Rayovac	Recharge Plus D2 Rechargeable Batteries	3000	Holds charge for 1 year
5. Energizer	Recharge D2 Nickel-Metal Hydride Rechargeable Batteries	2500	Not enough information provided
6. Duracell	Rechargeable D Cell Nickel-Metal Hydride Batteries	2200	Not enough information provided

A spreadsheet detailing the additional attributes of the 14 D-cell NiMH rechargeable batteries that were analyzed for this report can be found in Appendix C (see tab labeled "D Batteries").

BEST PRACTICES FOR PURCHASING AND USING RECHARGEABLE BATTERIES

- Include rechargeable batteries that meet the recommended specifications in the purchaser's Market Basket, Core or Bid List to ensure best discount prices.
- Test potential battery brands to verify performance (even brands that list similar specifications do not always result in equivalent performance).
- Beware that many combination products that include a battery and a charger together contain rechargeable batteries with a relatively low capacity (mAh) rating compared to other batteries with the same brand name.
- Store batteries at room temperature. "Cold temperatures cause the electrochemical reactions that take place within the battery to slow down. . . . Conversely, as temperatures

[8] This product is listed on the Amazon website, but not on the manufacturer's website. It may be discontinued.

rise, the electrochemical reactions within the battery become more efficient and effective resistance can decrease."[9] In other words, batteries operate more effectively in warmer weather, although they have a longer shelf life when stored at cooler temperatures. The common recommendation to store batteries in a freezer or refrigerator may introduce condensation, which can damage the battery. They are best stored in a cool, dry place at normal room temperature.

- Require chargers to have individual stations for each battery rather than paired or circuit stations. Since chargers without individual stations will often stop running when the first battery is fully charged, they can prevent the second battery from reaching a full charge. (Some dual-station chargers keep going until the second battery is fully charged, which can overcharge the first battery that reaches a full charge.)

- Also, look for chargers that offer "slow" or "gentle" charging, about 500 mA (.5 A) or less for AAs and about 200 mA (.2 A) or less for AAAs". Charging at high speeds (i.e., quick charging) can reduce the number of times a battery can be recharged.

John McGraw, customer service technical advisor at Energizer, recommended[10]:

- Purchase rechargeable batteries with the highest mAh possible.
- Do not "mix and match," choose a high mAh "battery that will meet all needs
- "Pre-charged" batteries arrive ready for immediate use but not fully charged because of shipping concerns and shelf life loss. The full benefit of NiMH batteries results from recharging to full capacity.
- The recharging process is key to maximizing performance and extending the life of the battery. Chargers often operate in pairs or on a circuit and stop charging when one of the batteries is filled, potentially leaving the others incompletely charged. However, some chargers do charge cells independently so that each achieves a full recharge.

GLOSSARY OF TERMS [11]

Capacity – Electrical energy that a battery cell can deliver, expressed in milli-ampere-hours (mAhs).

Discharge – The conversion of the chemical energy of the battery into electrical energy, used to power equipment.

Drain – The power demand by equipment on the battery cell.

Low self-discharge (LSD) – A reduction in the typical loss of energy by a battery when not in use. Batteries (both single-use and rechargeable) also drain energy when in use over a long

[9] Alkaline Manganese Dioxide Handbook and Application Manual, *Energizer*, Version: Alk2.0, p. 9; http://data.energizer.com/PDFs/alkaline_appman.pdf

[10] Phone interview 2/17/15

[11] References – batteryspace.com, greenbatteries.com, batteryuniversity.com

period of time.

mAh – milli-Ampere hours – Specifies battery capacity or rating, an indication of how long a battery will provide service at a specific drain rate to a specific cutoff voltage. For example, a AA battery with a capacity of 2500 mAh would be able to operate equipment with a 100 milli-Amp energy demand for 25 hours. However, the actual capacity of a specific battery will vary depending on several factors, including battery freshness, effectiveness of recharging, equipment demand, and the specific test conducted to determine mAh.

Memory effect – A reduction in the longevity of a rechargeable battery's charge, due to incomplete discharge in previous uses. This problem was more common with early versions of nickel-cadmium and nickel-metal hydride batteries, and is apparently uncommon with modern rechargeable batteries and chargers.[12]

Pre-charged – A rechargeable battery shipped with partial charge so that it can be used immediately rather than requiring an initial charging before use. While a pre-charged battery will run equipment for a short time, it will require charging to provide full capacity.

Self-discharge – Loss of energy while the battery is unused, due to internal leakage, during storage. (Rechargeable batteries labeled low-self-discharge (LSD) have a significantly lower discharge rate when the battery is not in use or when it is used over a long period of time in a low-drain application such as a clock or computer mouse.)

Shelf Life – The period of time that a battery retains a specified percentage of its original energy content when not in use.

Volt – The power rating of the potential electricity available in a battery.

COMPARISON OF BATTERY CHEMISTRY TYPES

Types of Batteries

- **Alkaline** – Single-use battery
- **Lithium Ion** – Rechargeable
- **NiCd** – Rechargeable Nickel Cadmium
- **NiMH** – Rechargeable Nickel-Metal Hydride (1. standard, 2. Low-self-discharge)
- **NiZn** – Rechargeable Zinc
- **Rechargeable Alkaline**

Single-Use Batteries

Alkaline

[12] "Definition: Battery Memory Effect," Whatis.com, http://whatis.techtarget.com/definition/battery-memory-effect, Last Updated May 2015

Single-use alkaline batteries are readily available and inexpensive. However, the State of California categorizes all batteries as *Universal Waste* because of the heavy metals and/or other toxic or corrosive materials they contain. Therefore, they must be recycled or disposed of in a household hazardous waste management facility.[13] Alkaline batteries are now being made with either no, or greatly reduced, mercury compared to earlier versions.[14]

The environmental and cost advantages of NiMH batteries over single-use alkaline batteries are apparent when these two products are compared over their full lifecycles. NiMH batteries can be recharged hundreds of times, enabling each rechargeable battery to replace hundreds of alkaline batteries over its service lifetime.

While the power – measured as available capacity – of a rechargeable battery is expressed in mAh, there is no comparable rating for alkaline batteries because their capacity varies significantly depending on the drain rate of the equipment in which they are used.[15] Alkaline batteries can only deliver their full capacity if the power is used slowly (e.g., if it is used to run a clock vs. a digital camera).[16] This makes it difficult to accurately compare single-use and rechargeable batteries.

Alkaline batteries typically have a sloping, or declining, voltage discharge curve. This means that their voltage decreases over time. Most devices are designed to operate within a voltage range that accommodates this sloping voltage discharge characteristic.[17] Some devices have a built-in "energy gauge" to assess how much capacity remains. An energy gauge must be calibrated to the battery's specific chemistry; therefore, some equipment may warn against using rechargeable batteries because the equipment's energy gauge is designed for alkaline batteries' sloping voltage discharge curve[18] rather than rechargeable batteries' flat voltage discharge rate.

Rechargeable Batteries

Nickel-Metal Hydride (NiMH)

In NiMH rechargeable batteries, the original nickel-cadmium (NiCd) electrode has been replaced with a nickel-metal hydride (NiMH) electrode[19]. This results in a less hazardous battery design since cadmium is a more toxic and bioaccumulative heavy metal than nickel.

Another benefit of NiMH AA batteries is that those with a high capacity rating (measured in mAh) can surpass alkaline batteries' performance in high-drain applications (e.g., digital

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[13] CalRecycle Waste Prevention Information Exchange: Batteries, http://www.calrecycle.ca.gov/reducewaste/Batteries/

[14] Energizer, http://www.energizer.com/batteries/energizer-max-alkaline-batteries, accessed 3/8/15, and Stanford Magazine, July/August 2011, https://alumni.stanford.edu/get/page/magazine/article/?article_id=43035, accessed 2/24/16

[15] John McGraw, *Energizer* Application Support, phone interview, 02/17/15

[16] All-Battery.com Rechargeable Battery Knowledge Base, Q4

[17] Energizer, *Alkaline Manganese Dioxide Handbook and Application Manual Version: Alk2.0*, p. 3

[18] John McGraw, *Energizer* Application Support, phone interview, 02/18/15

[19] Energizer, *Nickel Metal Hydride (NiMH) Handbook and Application Manual Version: NiMH02.01*, 2010, p. 2 http://88.198.249.35/d/Hybrid-Nickel-Metal-Hydride-Batteries.pdf

cameras, video game controllers). The overall advantage of NiMH batteries over single-use alkaline batteries is apparent when these two products are compared over their full lifecycles. NiMH batteries can be recharged hundreds – and in some cases thousands – of times, enabling each battery cell to replace hundreds or thousands of alkaline batteries over its service lifetime.[20]

Another advantage of NiMH batteries is their stable performance due to a flat discharge curve. This means that a NiMH battery will remain in high voltage during 80% of its usage cycle,[21] compared to the consistently declining discharge curve of single-use alkaline batteries. While this flat discharge feature provides steady capacity for the life of the battery, it also makes determining the remaining life of the battery difficult. For this reason, rechargeable batteries are often discouraged for medical and safety equipment, since at the end of their capacity they can stop working without warning.

NiMH batteries have gone through several "generations" of development and improvement. In 2005, Sanyo introduced the Eneloop battery, which was both pre-charged, allowing immediate use rather than requiring an initial charging time, and low self-discharge (LSD). Some non-LSD NiMH batteries lose approximately 0.5-4% of their capacity per day when stored unused and, therefore, require periodic recharging even when not in use.[22] In comparison, the Eneloop batteries lose only 10% of their capacity over the first year and still maintain 70% after five years.[23] Standard AA rechargeable Eneloop batteries hold 2000 mAh capacity and can be recharged 1800-2100 times. A high capacity Eneloop battery, with 2550 mAh, retains 85% of its charge up to one year, although it can only be recharged 500 times.

Meanwhile, other major battery manufacturers such as Energizer and Duracell have, over the years, improved their own NiMH batteries to include similar pre-charged and LSD features. Therefore, the advances introduced by the Eneloop technology are now available from both Sanyo and Panasonic, as well as several competing companies, including Energizer (Recharge Power Plus), Rayovac (Recharge Plus) and Duracell (Rechargeable Batteries).

The City of Portland, EPA Region 9, and the University of Florida tested NiMH AA batteries rated 2300 mAh. They are used for flashlights, alarms, headsets, computer mice, keyboards, label makers, wall clocks, toilet flush valves, and more. Caltrans uses rechargeable AA batteries in digital cameras and walkie-talkies. In 2014, CalTrans reported that it did not use rechargeable batteries in timers and clocks because, in its experience, they did not last as long as single-use alkaline batteries in this equipment, yet the remaining charge cannot be easily assessed. (The newer LSD rechargeable batteries can be expected to have significantly greater longevity.) The University of Florida found they could not use rechargeable batteries for the voltmeters they use for testers because the built-in remaining-capacity gauges are designed for the sloping discharge curve of alkaline batteries.

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[20] Ibid.

[21] All-Battery.com Rechargeable Battery Knowledge Base, Q3

[22] *World Heritage Encyclopedia*, http://www.worldlibrary.org/articles/nickel_metal_hydride_battery, accessed 2/24/16

[23] Eneloop, Wikipedia, http://en.wikipedia.org/wiki/Eneloop, accessed 3/5/15

Lithium Ion (Li-Ion)

At first, lithium ion (Li-Ion) batteries appear to be a strong contender for highest quality rechargeable batteries. With a voltage of 3.7 and typical mAh of up to 3000, these batteries clearly have extraordinary capacity compared to other rechargeable batteries. They also can pack that capacity into a much smaller and lighter battery size and lithium ion batteries are currently an extremely popular research focus.

But expert interviews revealed that Li-Ion rechargeable batteries are not recommended for the independent consumer market.[24] One reason for this is that Li-Ion batteries are generally not standardized to the AA size of other battery chemistries. While some Li-Ion sizes are close, these batteries tend to be slightly longer than AA batteries, in measurements that vary by brand as well. In fact, they may not conform to typical battery sizes precisely to discourage consumers from substituting them for their alkaline or NiMH batteries. With a voltage 2-3 times higher than other batteries, using a Li-Ion battery could damage or destroy the battery-operated equipment.

In addition, while there are extra safeguards built into these batteries, there is still some danger from explosion or fires, particularly when charging them. Therefore, researchers and equipment designers are tending towards combining lithium ion batteries into sealed packs that are specially designed for specific equipment such as cameras and mobile phones.

Nickel Cadmium (NiCd)

NiCd rechargeable batteries are valued for use in some equipment such as portable power tools that require high initial and sustained energy delivery. In addition, they are sometimes used in specialized applications such as outdoor lighting, and some flashlights. However, NiCd rechargeable batteries no longer appear to be appropriate for use in general office and field equipment. One reason is because they can suffer from "memory effect," which lowers the capacity of a NiCd battery if it has not been fully discharged before being charged. NiCd batteries contain toxic metals (cadmium) and are not environmentally friendly.

Rechargeable Alkaline

Rechargeable alkaline batteries were introduced into the market in 1992 but have not achieved significant market share, largely because other types of rechargeable batteries offer more features, including far more rechargeable lifetimes. For example, they can only be recharged up to approximately 50 times (depending on their equipment use and how they are recharged) and each recharge produces a shorter charge life.

Nickel Zinc (NiZn)

NiZn AA rechargeable batteries made a splash in 2009, soon after their introduction by PowerGenix in San Diego, when they were recognized as one of the "Top 100" innovations of

[24] Matthew Ganter, Rochester Institute of Technology, phone conversation on 2/17/15

2009 in *Popular Science*.[25] However, they were discontinued soon afterwards when their manufacturer decided to turn its expertise to developing NiZn batteries for electric cars instead.

Despite their standard voltage of 1.6V, their capacity is much lower than that of nickel-metal hydride batteries. For example, PowerGenix claimed a combine power rating of 750 mAh for two AA NiZn batteries and 1500 mAh for four AA NiZn batteries. (Most NiMH AA batteries have a capacity of 2000 mAh each.)

A MetaEfficient.com review[26] reported that NiZn rechargeable batteries:

- Perform well in high-drain devices that require a high voltage
- Tend to go flat after about 30-50 recharges, although PowerGenix claimed 100-500 cycles
- Require a special charger optimized for their chemistry
- Can be hazardous to many battery-operated appliances because, when freshly charged, terminal voltage is about 1.85V (before settling into its standard of 1.6V)
- Are valuable for recycling because of the demand for nickel

APPLICABLE STANDARDS

There currently are no environmental certifications or performance standards for rechargeable (or single-use) batteries. Several years ago, EcoLogo had a standard for rechargeable batteries, but it no longer exists. There are safety standards for batteries, however. For example, both the International Electrotechnical Commission (IEC)[27] and the American National Standards Institute (ANSI) publish standards for portable (i.e., consumer) batteries. Both require that the standards be purchased so they were not available for full review. But the organizations value synchronizing their standards with each others.[28] UL also has battery standards and one of their engineers sits on the committee that designed ANSI's current standards.[29] According to their engineer, UL's battery standards primarily reference safety issues and not performance or environmental sustainability.

Relevant standards include:

IEC 61951-Part 1 – Covers testing method to determine battery life cycle, regardless of type of chemistry[30]

IEC 61951-Part 2 – Specific to NiMH batteries, includes method for determining capacity (mAh), updated 2011[31]

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[25] "Popular Science Names PowerGenix's NiZn Batteries 'Best of What's New' Winner," *Popular Science*, November 12, 2009, http://powergenix.com/popular-science-names-powergenixs-nizn-batteries-best-of-whats-new-winner/

[26] MetaEfficient, "A Review of NiZn Batteries," August 7, 2015; http://www.metaefficient.com/rechargeable-batteries/nizn-batteries.html

[27] http://www.iec.ch/

[28] John McGraw, *Energizer* Application Support, phone interview, 02/17/15

[29] Laurie B. Florence, Principal Engineer, UL, interviewed 1/23/15

[30] Raymond Ng, AA Portable Power Corp.

[31] Ibid., 2011 update requires purchase, but Ng referenced 2003 version as representative and close to the updated version

ANSI C18.2M-Part 1 – Specifies dimensions, includes some applicability to performance[32] and specifies method for testing capacity (mAh)
ANSI C18.2M-Part 2 – Primarily covers safety tests[33]

COMPARISONS OF AA BATTERY CHEMISTRIES

	Alkaline Single Use	NiMH Rechargeable Standard	NiMH Rechargeable LSD	Lithium Ion Rechargeable	NiCd Rechargeable	NiZn Rechargeable
Voltage	1.5V	1.2V	1.2V	3.6V	1.2V	1.6V
Capacity (mAh)	2500-3000, but only partially accessible in high-drain equipment (yielding only 700-1000 mAh)	Range, from 1000 up to 2800	Range, from 2000 up to 2800	Range, up to 3000	Range, up to 1000	1500
Length of One Use	Varies by brand, lasts longer than NiMH for low-drain, less than NiMH for high-drain equipment	Exceeds Alkaline at high-drain rates	Exceeds Alkaline at high drain rates	Not appropriate for single-cell battery use in traditional equipment; primarily used in specially-designed battery packs	Half of NiMH or less	Depends on equipment, often exceeds NiMH
Immediate Use	Yes	No	Yes, Pre-Charged (but this is not full-charge)	No, cannot be shipped pre-charged (safety issues), needs charging	No	NA
Discharge in Use	Sloping discharge, from 1.5V to less than 1.0V in course of use	Relatively flat, steady discharge, remaining at 1.2V for most of cycle, then drops quickly at end	Relatively flat, steady discharge, remaining at 1.2V for most of cycle, then drops quickly at end	N/A	Higher initial discharge than NiMH, good for power tools	Good for high drain devices

[32] Laurie B. Florence, UL Principal Engineer, 1/23/15
[33] Ibid.

Discharge in Storage	Minimal, retains 80% at 7 years	Loses 4% per day, retains 50-80% at six months	Retain 85-90% capacity at one year, 70% after five years	N/A	20% per month	8-13% per month
	Alkaline Single Use	**NiMH Rechargeable Standard**	**NiMH Rechargeable LSD**	**Lithium Ion Rechargeable**	**NiCd Rechargeable**	**NiZn Rechargeable**
Life Cycle	Single use, no recharging	Varies by brand and model, 300 – 3000 life cycles	Varies by brand and model, 300 – 3000 life cycles	300-1000	1500	30-50, more for some uses
Benefits	Cheap, convenient, widely available	Power stays steady (approx. 80%) for almost all battery life, can be recharged hundreds of times, less toxic than NiCd, nickel is valuable recycling	Power stays steady (approx. 80%) for almost all battery life, can be recharged hundreds of times, less toxic than NiCd, nickel is valuable recycling	Lightweight, allows downsizing of equipment, high capacity	Higher initial discharge than NiMH	Performs well in high drain devices, nickel is valuable for recycling
Drawbacks	Not recharge-able or recyclable	Remaining capacity hard to determine so not appropriate for safety and emergency equipment	Remaining capacity hard to determine so not appropriate for safety and emergency equipment	Currently not in standard AA sizes, voltage too high for non-specialized equipment; primarily used in battery packs; safety concerns in recharging and shipping	Exhibits "memory effect" when charged after incomplete discharge, cadmium is a toxic heavy metal	Freshly charged terminal voltage is about 1.85V, which can be hazardous to many appliances, nickel and cobalt are considered possibly carcinogenic

Sources: *Nickel-Metal Hydride (NiMH) Handbook and Application Manual/Energizer*, *Batteries In A Portable World,* Eneloop/Wikipedia, Gizmag (http://www.gizmag.com/4x-8x-lithium-batteries-power/13134/), MetaEfficient (http://www.metaefficient.com/rechargeable-batteries/nizn-batteries.html), Michael Bluejay (http://michaelbluejay.com/batteries/rechargeable.html#niznm), PowerGenix (http://powergenix.com/wp-content/uploads/2014/03/powergenix_nizn_msds_2.pdf

COST COMPARISONS

Exacting theoretical cost comparisons between alkaline single-use batteries and NiMH rechargeable batteries are not possible because of the range of variables involved. These include comparable capacities (mAh), type of equipment use and energy-drain, shelf-life, and effectiveness of recharging processes, as well as significant differences between brands of batteries (both alkaline and rechargeables). An additional "soft" cost is the experience noted by at least two interviewees that alkaline single-use batteries seem to "walk away" more frequently than rechargeables, especially around holidays. However, following are cost comparisons that give some illumination to the question.

University of Florida Physical Plant Division, Range of Batteries, Contract Prices		
	Alkaline Single-Use	NiMH Rechargeable
Year	12/1/10-12/1/11	11/1/13-11/1/14 (replacement and additional batteries, not the initial investment year)
AA	$1404.48 = 6688 batteries	$791.56 = 909 batteries
AAA	$666.13 = 2297 batteries	$1493.76 = 594 batteries
C	$577.92 = 516 batteries	$64.00 = 64 batteries
D	$510.80 = 1277 batteries	$696.06 = 178 batteries
9V	$757.95 = 489 batteries	$220.00 = 220 batteries
Chargers	Not applicable	$367.64 = 16 chargers
Total Cost and # Batteries	$3,917.28 = 11,267 batteries	$3,633.02 = 1965 batteries
Results: Prior to using rechargeables, the University of Florida Physical Plant Division was disposing of more than 11,000 batteries per year. After switching to rechargeables, there would be no batteries needing disposal for at least 2-3 years. The rechargeables in this spreadsheet are primarily additional batteries and do not represent the initial investment, which is still in use.		

Missouri State Recycling Program, AA Batteries, State Contract Prices 2008		
	Alkaline Single-Use	NiMH Rechargeable
Contract Prices	$1.52 = 4 AA batteries @ .38/each	$14.50 = 2 4-packs AA batteries (1 set in use, 1 set recharging) $30.46 = charger
300 Uses	$456	$44.96
1000 Uses	$1520	$44.96

REPORT REFERENCES

Alkaline Manganese Dioxide Handbook and Application Manual, *Energizer*, Version: Alk2.0, 2008-2012, http://data.energizer.com/PDFs/alkaline_appman.pdf

All-Battery.com Rechargeable Battery Knowledge Base, http://www.all-battery.com/batterybasics.aspx#Q4.%20What%20does%20battery%20%E2%80%9CmAh%E2%80%9D%20capacity%20mean

CalRecycle Waste Prevention Information Exchange: Batteries, http://www.calrecycle.ca.gov/reducewaste/Batteries/

Nickel Metal Hydride (NiMH) Handbook and Application Manual, Energizer, Version: NiMH02.01, 2010, http://data.energizer.com/PDFs/nickelmetalhydride_appman.pdf

NiMH Battery Chargers Handbook and Application Manual, Energizer, Version: Chg1.4, 2008, http://data.energizer.com/PDFs/charger_appman.pdf

APPENDIX A
Benchmarking Assessment

This section of the report describes what several federal agencies, local governments, state agencies and universities have learned when they evaluated or pilot tested rechargeable batteries for their operations. It is important to note that few of these entities appear to be using high-capacity NiMH rechargeable batteries with LSD technology. Consequently, more pilot tests comparing rechargeable batteries that meet RPN's proposed specifications with single-use, alkaline batteries are needed.

City of Portland, OR – Stacey Foreman, Sustainable Procurement Coordinator, Procurement Services, November 2014

- Procurement office (40-person) has made rechargeable batteries available to its staff for approximately three years.
- AA (2300 mAh) and AAA (700 mAh) rechargeable batteries used in keyboards, mice, and other office accessories.
- Staff pick up charged batteries at central location in supply room and drop off spent batteries to be charged.
- Stacey, as a member of the Green Team, checks the batteries and charges them, also "refreshes" them once a month.
- Some staff members say they have to change batteries more often.
- Single-use batteries are available only by request, while the rechargeables are "self-serve."
- Single-use batteries still tend to be used for flashlights and some camera equipment.
- Recommends marking rechargeable batteries with the date they are put into service, to identify and remove those that are getting near the end of their effective lifecycle, in order to prevent dissatisfaction with rechargeables' battery life. They have not yet reached the end-of-life for their original rechargeable batteries.
- Keys to success: 1) Champion who is empowered to take on making the change, and 2) Management approval.

King County, WA – Karen Hamilton, Environmental Program Purchasing Manager, November 2014

- The Purchasing Department uses rechargeables in their office camera.
- The Solid Waste Division has piloted a small project with a staff person designated as responsible for charging the batteries, near the end of their anticipated charge, in order to prevent dissatisfaction with the rechargeables.

Missouri State Recycling Program – Bob Didriksen, State Recycling Coordinator, forwarded a PowerPoint presentation he made to the Missouri Association of Public Purchasing 2008 Fall Conference, in which he calculated a cost comparison between alkaline and NiMH rechargeable AA batteries:

Alkaline Single-Use AA Batteries (State contract pricing)
4 AA batteries @ $.38/each = $1.52
x 300 uses (conservative estimate of comparable rechargeable life-cycle) = $456

NiMH Rechargeable AA Batteries (State contract pricing)
Charger = $30.46
4-pack AA = $7.25 x 2 (1 set in use, 1 set recharging)
x 300 uses = $44.96 (cost would also be the same for 1000 uses)

300 Uses - $456 Alkaline single-use batteries vs. $44.96 NiMH rechargeables
1000 Uses - $1520 Alkaline single-use batteries vs. $44.96 NiMH rechargeables

Naval Postgraduate School – Captain Darrell H. Brown, Marine Corps Graduate Student

- In 2011, he wrote his thesis for master's degree in management from NPS' Graduate School of Public Policy on making a case for use of rechargeable batteries in a typical Marine Corps infantry battalion.[34]
- His team analyzed the full costs of purchasing, delivering, using and disposing of rechargeable vs. non-rechargeable batteries through the full life-cycle.
- Brown discovered that the more batteries a battalion need, and the longer it is in the field, the more money could be saved.
- He reported that the initial investment cost of rechargeable batteries can be recouped in a few weeks. Additional benefits include avoided disposal costs and the reduced need for storage space.[35]

State of California Burke Lucy, CalRecycle's rechargeable batteries expert, sent survey emails to many State departments in December 2014. Caltrans reported on their use.

- *Caltrans* - District 9 (Inyo, Mono and eastern Kern Counties) uses rechargeable batteries for cordless tools (such as cordless drills) and as back-up batteries in emergency exit lights and lit exit signs.
- They also use some rechargeable AA batteries and report that they work acceptably in digital cameras and walkie-talkies.
- They have found rechargeable batteries unacceptable in timers and clocks because, in their experience, the (non-LSD) rechargeable batteries did not last as long as single-use alkaline batteries and the remaining charge could not be easily monitored in this equipment.

[34] "Marine Corps Student Analyzes Cost Savings of Rechargeable Batteries Over Disposables," 2011; http://www.nps.edu/About/News/Marine-Corps-Student-Analyzes-Cost-Savings-of-Rechargeable-Batteries-Over-Disposables.html, accessed 2/26/16

[35] This return on investment analysis includes many military-grade batteries, which are much larger than standard consumer sizes such as AA, AAA, and D cells. However, it includes important lessons learned about the benefits of switching to rechargeable batteries.

U.S. Army – Case Study of Army Battery Standardization, 2002[36]

- The Army was experiencing increased demand for portable power, leading to rising battery expenditures and a proliferation of battery types. At the same time, battery manufacturers were increasingly reluctant to manufacture military batteries because of low volume. Soldiers needed a dependable supply and light weights, since they independently carried power for more equipment.
- The Army standardized battery sizes, dramatically reduced the number of non-rechargeable batteries in new equipment, and increased the use of rechargeable batteries.
- This is an old case study, covering a change to NiCd batteries starting in 1997 and included larger batteries as well as small, consumer batteries.
  Nevertheless, the Army projected savings of $33 million over 7 years, and actually achieved a savings of more than $43 million in just 4 years by using rechargeable batteries instead of single-use batteries.

U.S. Department of Energy (US DOE) – Sustainable Acquisition Program, February 2016

- US DOE's Green Buy Program has a goal for batteries that they be rechargeable.
- One of the DOE sites found Eneloop low self-discharge rechargeable batteries (AA size with D-sized adapters) were comparable in operation and longevity to standard alkaline batteries when used in automatic paper towel dispensers. While the rechargeable batteries were more expensive initially, the fact that they can be recharged and reused means the cost for batteries is reduced.
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U.S. Environmental Protection Agency (EPA) Region 9 - Amitkumar Raikar, Contracting Officer

- In 2011, US EPA Region 9 kicked off a conversion to using rechargeable batteries with educational presentations introducing the new batteries, explaining the process for recharging them, and confirming that single-use batteries would be discontinued except for specific uses. Subsequent follow-up presentations reinforced the information.
- EPA Region 9 actually uses very few batteries, primarily for wall clocks and less common office equipment such as label makers. A few staff members use cordless mice. Prior use of battery-operated phone call headsets has been phased out.
- Single-use alkaline batteries are still purchased for use in safety equipment such as emergency defibrillators.
- The AA rechargeable batteries on-hand are Energizer Recharge, 2300 mAh.
- Staff members needing batteries are encouraged to pick up two sets at the supply center, to have one for back-up. Rechargers are on most floors in the copier rooms; staff recharge and refresh their batteries independently.
- This was primarily an informal project and did not result in reports or data collection, other than tracking and responding to concerns. The number of concerns has dropped considerably as the program has become familiar and problems have been resolved. Examples of problems were 1) people taking others' batteries from the rechargers, solved

[36] US Army, Defense Standardization Program Case Study, Army Battery Standardization: Rechargeable Batteries Power the Future Force, 2002; Case-Study-Army-Battery-Stanardization.org.pdf

by labeling batteries with the users' names, and 2) needing to inform staff that alkaline single-use batteries could not be put into the rechargers.

- The Purchasing office handles large dollar-amount purchases and, therefore, does not have data on the batteries, which are handled by individual offices and branches in small office purchases. Once the single-use batteries were discontinued, the amount of e-waste collected dropped considerably.

U.S. Forest Service

Mt. Baker-Snoqualmie National Forest, Pacific Northwest Region – The largest use of alkaline batteries was for hand-held radios. Users were interested in purchasing lithium ion (Li-Ion) rechargeable batteries to replace equipment that used older nickel-cadmium rechargeables and alkaline batteries, but the high cost per battery ($45.86) was an obstacle and their reliability was unconfirmed. Three Fire and Recreation programs collaborated on requesting a Forest Service micro-grant to make the purchases.

- Time Period: 2013
- Replacement Value: Each Li-Ion radio battery replaced 3-12 packs of AA alkaline batteries over the summer season
- Cost Savings: Each Li-Ion battery saved $45 over a three-year lifespan
- Waste Reduction: Each Li-Ion battery reduced 110 pounds of AA alkaline batteries
- Additional Benefits: Increased radio reliability, communication abilities, and employee safety

Tahoe National Forest, Pacific Southwest Region – Provided Li-Ion rechargeable clamshells to 12 users in order to study effectiveness of rechargeable batteries for radio use. Users logged recharge dates and voltage of recharged battery, as well as their radio use in the field.

- Time Period: Summer 2014
- Estimated Payback: 17 weeks
- **Savings**: **$234/user for first year, $634/user over two years**

Tongass National Forest, Alaska Region – The Juneau Ranger District and Admiralty Islands National Monument desired to replace alkaline single-use batteries with NiMH rechargeable batteries, whenever possible, in order to reduce battery waste and disposal costs. Wilderness and Recreation Groups quantified the need for AA, AAA and C batteries for use in trail counters, flashlights, GPS units and other equipment. The District purchased two battery chargers, 36 NiMH C batteries and 24 NiMH AA batteries.

- Time Period: Summer 2014
- Goal: Reduce small battery waste by 40 lbs./year
- Experience: Wildlife Shop at the Juneau Ranger District has been using NiMH batteries for 5 years with mostly good results, although some batches of batteries do not have the expected longevity.

University of Florida, Physical Plant Division – Allen Masters, Assistant Director

- They converted to rechargeable batteries in 2012, using AA, AAA, C, D, 9V, 6V
- They chose the EverReady Energizer Recharge brand of NiMH rechargeable batteries in order to have a complete system from one company, including AA PowerPlus batteries = 1.2V, 2300 mAh, pre-charged.
- The AA rechargeable batteries are used in flashlights, alarms, toilet flush valves (some use 9V instead), headsets, mice, keyboards, more. They cannot use them in the voltmeters they use for testers; signage on the voltmeters says not to use rechargeables. (Equipment with built-in remaining-capacity gauges to test battery capacity are designed for specific batteries, such as the sloping discharge curve of alkaline batteries and, therefore, are not approved for other types of batteries.[37])
- They use a "counter dispensing system" in which users come to the physical plant warehouse to buy batteries and chargers or exchange expended batteries for fresh ones. The warehouse keeps a rack of chargers there to recharge the returned batteries. Some users buy their own chargers and do their own recharging. They do not use chargers in trucks associated with field equipment because it takes too long and they have a "no idling" rule for trucks.
- They do not know how many times the batteries have been recharged but think they have not totally used up any of them yet. (Energizer advertises their PowerPlus AA batteries to be rechargeable up to 700 times.[38])
- They sent a spreadsheet comparing annual costs before and after the change to rechargeables, synopsized in the Cost section above. At the time of this interview, the university had not yet had to replace its initial rechargeable batteries. Therefore, the cost information reflects only additional battery purchases, not the original cost of the rechargeable batteries and chargers.

- ***Benefits***
  - Saves money
  - Redirects batteries to recycling instead of municipal solid waste (MSW), keeps hazardous wastes out of MSW
  - Better battery retention (batteries used to "walk away" near holidays)

- ***Drawbacks***
  - Batteries say they are "pre-charged" but last too short a time out of the package. Warehouse employees now charge them before giving them out. (Pre-charged Energizer batteries are shipped with only partial charge for safety reasons and because of shelf life losses; full capacity only comes from charging by user.[39])
  - The rechargeables seem to last less time than the alkaline batteries, but it depends on the equipment in which they are used.
    - They last a long time in low-drain equipment such as mice and keyboards, but do not perform as well in high-drain equipment.[40]

[37] John McGraw, *Energizer* Application Support, phone interview, 02/18/15
[38] http://www.energizer.com/batteries/energizer-rechargeable-batteries, accessed 3/8/15
[39] John McGraw, *Energizer* Application Support, phone interview, 02/17/15
[40] Note: The 2300 mAh rechargeable batteries reportedly in use have a capacity that is not as high as some other NiMH-LSD batteries, which could be expected to be most effective in high-drain equipment.

    - They had problems using them in flashlights until they switched the flashlights from incandescent to LEDs to reduce the power drain.
- Janitorial staff say they have to change the batteries in automatic flush toilets in high-use areas more frequently now. (This might result in slightly increased labor costs as well.)
- The universal chargers didn't work for recharging 9V batteries; separate chargers were needed for 9V batteries.
- They have not been able to buy the rechargeable batteries in bulk, although they had previously bought the single-use alkaline batteries in bulk. They are getting the Energizer batteries in blister 4-packs, which creates excess waste. (John McGraw at Energizer confirmed that they do not provide their rechargeables in bulk quantities. However, some other brands are available in bulk.)
- There might be slightly higher energy costs from using the chargers, but the switch to rechargeables was accomplished at the same time that they renovated their warehouse to provide energy system cost reductions, so any difference from use of the chargers is not apparent.

APPENDIX B
Contacts

ORGANIZATION	CONTACT NAME	CONTACT INFO
AA Portable Power/BatterySpace.com	Raymond Ng, Technical Support and Customer Service	Sales@batteryspace.com, 510-525-2328 x212, www.batteryspace.com
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